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PROSPECTING IN NEW BRUNSWICK (SESSION IV)

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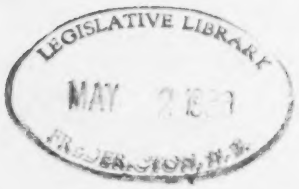

NATURAL RESOURCES
NEW BRUNSWICK
RESSOURCES NATURELLES
NOUVEAU-BRUNSWICK

Government of Canada / Gouvernement du Canada
Regional Economic Expansion / Expansion Économique Régionale

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Hon. Gerald S. Merrithew

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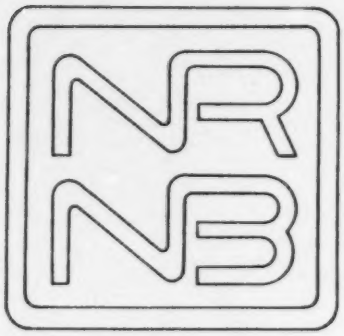
Hon. Herb Gray, Minister

PROSPECTING IN NEW BRUNSWICK
(SESSION IV)



Mineral Resources Division
Department of Natural Resources
New Brunswick

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Notes on

PROSPECTING IN NEW BRUNSWICK

BY

W.E. Hale

SESSION FOUR

Subsurface Processes and Geological Maps

February, 1981

Revised January, 1982

Notes on
PROSPECTING IN NEW BRUNSWICK
W.E. Hale

SESSION FOUR

Subsurface Processes and Geological Maps

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Notes on

PROSPECTING IN NEW BRUNSWICK

W.E. HALE

SESSION FOUR

(of six)

SUBSURFACE GEOLOGICAL PROCESSES AND GEOLOGICAL MAPS

4.1.0 SUBSURFACE PROCESSES

4.1.1 Introduction

Subsurface geological conditions, processes and products are less well understood than those of the surface for the obvious reason that we do not see them directly. Our evidence for what goes on below the surface, while extensive, is mostly indirect i.e. by inference from, or interpretation of, 'clues' such as earthquakes, volcanic eruptions, plutonic rocks and others.

For the purposes of this prospecting program, only the lines of evidence that support our understanding of the interior of the earth will be listed. Interested trainees who wish further information on this exciting subject may refer to References 2, 6, 10 and the bibliographies therein, particularly in Reference 6..

Our interpretation of the earth's subsurface is derived from the following:

1) The changes, particularly in temperature, that are observed at increasing depths below the surface in mines and deep drill holes,

2) The volcanic eruptions that bring subsurface material: molten rock, other liquids, and gases to the surface,

3) The rocks (igneous) now exposed on the surface (after uplift from deeper parts of the earth) that show evidence of once

having been molten,

4) The differences in the velocity of shock waves from earthquakes as these waves pass through the earth,

5) Heat flow on the earth's surface,

6) The density of surface materials and the earth as a whole,

7) Meteorites,

8) Experimental formation of rocks and minerals,

9) Metallurgy,

10) Magnetic changes in space and time, and,

11) Radioactivity.

Fig. 1 provides some facts relating to the earth and it's interior.

It may be worthwhile repeating the earlier comment about the dynamic or ever-changing nature of the earth. Most geological processes operate extremely slowly by comparison with other processes with which we as humans are familiar (e.g., weather processes: annual, seasonal, short-duration storms, daily temperature changes; biological processes such as the birth, maturation, reproduction and death of living organisms). The geological processes, diagrammatically depicted in simplified form in the rock cycle, (provided in a previous session) operate continuously although not at a constant rate. The rate, or intensity, of a given process in the generalized cycle will vary from time to time and from place to place on and in the earth.

Another problem with understanding subsurface processes arises from the difficulty in imagining the source and magnitude of the energies required, for example, to deform and uplift a mountain range such as the Alps, Himalayas, Andes or Rockies. On the earth's surface it's not too difficult to appreciate that the

FIGURE 1. - Earth Facts Source: Holmes, 1978, Principles of Physical Geology, 3rd ed., Thomas Nelson and Sons Ltd., England.

Some Numerical Facts about the Earth

Land			Oceans and Seas		
Greatest known height:	*Feet*	*Metres*	*Greatest known depth:*	*Feet*	*Metres*
Mount Everest	29,028	8,848	Marianas Trench	36,204	11,035
Average height	2,757	840	Average depth	12,460	3,808

Size and Shape	*Miles*	*Km*	Area	*Millions Sq. Miles*	*Millions Sq. Km*
Equatorial semi-axis, *a*	3,963·2	6,378·2	Land (29·22 per cent)	57·5	149
Polar semi-axis, *b*	3,950·0	6,356·8	Ice sheets and glaciers	6	15·6
Mean radius	3,956·4	6,371·0	Oceans & seas (70·78 per cent)	139·4	361
Equatorial circumference	24,902	40,076	Land plus continental shelf	68·5	177·4
Polar (meridian) circumference	24,857	40,009	Oceans & seas minus continental shelf	128·4	332·6
Ellipticity, $(a+b)/a$	1/298		Total area of the earth	196·9	510·0

Volume, Density and Mass	*Average thickness or radius (km)*	*Volume ($\times 10^8$ km^3)*	*Mean Density (g/cm^3)*	*Mass ($\times 10^{24}$ g)*
Atmosphere	—	—	—	0·005
Oceans and seas	3·8	1,370	1·03	1·41
Ice sheets and glaciers	1·6	25	0·90	0·023
Continental crust*	35	6,210	2·8	17·39
Oceanic crust†	8	2,660	2·9	7·71
Mantle	2,881	898,000	4·53	4,068
Core	3,473	175,500	10·72	1,881
Whole Earth	6,371	1,083,230	5·517	5,976

*Including continental shelves
†Excluding continental shelves

Conversion factors

1 miles	= 1·609 km	1 km	= 0·621 mile
1 foot	= 0·3048 metre (m)	1 m	= 3·281 feet
1 sq. mile	= 2·59 km^2	1 km^2	= 0·386 sq. mile
1 cubic mile	= 4·17 km^3	1 km^3	= 0·24 cubic mile

sun's heat, gravity, rain, ice and running water are adequate, over long periods of time, to wear down solid rocks and transport them to the sea. Multiplying this observable (in some places) process by 1000's of similar examples, operating over 1000's of years, and it may be possible to accept the idea of a whole mountain range being reduced to or near sea-level (as has happened in N.B.). But what of the energy and process(es) required to produce the mountain range?

Subsurface processes include those that produce primary (see Rock Cycle, Session Three, p. 11) material or molten magma which may, under pressure, break through the surface in the form of a volcano or come to rest and cool at some depth below the surface. Also included are those processes that break, bend and otherwise alter previously formed rocks to produce 'new' rock types (metamorphic) that do not form anywhere on the surface yet may have relict characteristics strongly indicating that they were once sedimentary deposits.

Not only is there good evidenced of temperatures and pressures high enough to melt rocks below the earth's surface and alter them mechanically and mineralogically to form new types but a growing body of evidence supports the idea that large segments of the earth's crust are being moved about, pulling apart and colliding with other segments to produce rifts, deep trenches, mountain ranges and even the ocean basins themselves (plate tectonics).

4.1.2 Geologic Time

Time, in the geological sense, is probably the most difficult concept for the non-geologist to understand. Misunderstanding and controversy concerning the immensity and

measurement of geologic time prompted heated debate between scientists and others during the last century. (An interesting account of this controversy may be found in Birth and Development of the Geological Sciences, F.D. Adams, 1954, Dover Publications, Inc.).

Geologic time has been referred to earlier in this program but further comment may be warranted to help understand slower geological processes taking place out of sight, beneath the surface.

The geological time scale is the 'calendar' of geological events since the formation of the earth or, more precisely, since the formation of a solid crust on the earth. This record is built up and filled in by many scientists working from many different directions of inquiry. Two main types of geological age dating are used.

Relative age is, as the name suggests, the establishment of an older-younger relationship between two rock types, for example, without knowing the actual number of years since the formation of either rock. A simple example of this type of age determination may be found in many gravel or sand pits or along banks of rivers where the sediments are layered. In an undisturbed section in the banks, the older deposits will naturally be on the bottom and 'younging' will be upward, through the section, to the surface where the most recent deposits may include decaying tree and plant remains mixed with modern garbage. This simple example serves to demonstrate one way in which age is determined among geological materials without assigning numbers of years. The method is applied to older and

more complex geological situations in essentially the same way to piece together a sequence of geological events. Relative age determinations are made with greater confidence and over large areas where fossils are present in the sediments or sedimentary rocks.

Absolute age determinations provide us with the means of assigning an actual number of years to individual rock types, commonly igneous. The method depends on the discovery, made near the beginning of this century, that certain naturally occurring, radioactive elements available in the fluid material inside the earth may become 'locked into' mineral compounds at the time those minerals crystallize. These radioactive elements, such as uranium, thorium, potassium, disintegrate slowly and at a constant rate to produce other elements distinguishable from the "parent". If there is no removal or addition of elements, to or from the mineral, from the time of its original formation, we can remove it from the rock, determine the amount of parent and daughter elements present, and knowing the rate at which one is produced from the other, calculate the time in years since the mineral crystallized. Not all rocks contain sufficient radioactive elements to permit absolute age determinations so the method cannot be applied to all geological materials.

These two approaches to geologic age determination have permitted the building up of a geological time scale for the history of our planet. The record is incomplete and is being 'filled in' by geologists using both methods all over the world.

A time scale is provided in Fig. 2 and serves as a summary of world geological events. It may also contribute to an

THE GEOLOGICAL TIME-SCALE

Era	Periods	Epochs	Derivation of Names	Approx. Duration	Approx. Time to Beginning	Distinctive Life
				(Millions of Years)		
						Modern Man
						Stone-Age Man
Cainozoic	Quaternary	Recent				
		Pleistocene	*Pleiston* = most	2	2	Great variety of Mammals
			Greek: Refers to proportion of fossil marine shells + 'cene', from *Kainos* = recent			Elephants widespread
	Tertiary	Pliocene	*Pleion* = more	3	5	Flowering plants in full development. Ancestral dogs and bears
		Miocene	*Meion* = less	17	22	Ancestral pigs and apes
		Oligocene	*Oligos* = few	14	36	Ancestral horses, cattle and elephants
		Eocene	*Eos* = dawn	17	53	Extinction of Dinosaurs and Ammonites
		Paleocene	*Palaios* = old	12	65	Mammals and Flowering plants slowly appear
Mesozoic	Cretaceous		(Latin), *Creta* = chalk, abundant in N. Europe	70	135	Dinosaurs and Ammonites abundant
	Jurassic		From *Jura* Mountains	65	200	Birds and Mammals appear
	Triassic		From a former *threefold* division of rocks of N. Germany	40	240	Flying reptiles and Dinosaurs appear. First corals of modern types
Paleozoic	Permian		*Permia:* an ancient kingdom in E. Russia	40	280	Rise of Reptiles and Amphibians. Conifers and beetles appear
	Pennsylvanian		From the state of *Pennsylvania* In Europe, called *Carboniferous* (= coal-bearing).	90	370	Coal forests. First Reptiles and winged insects
	Mississippian		From the *Mississippi* Valley	45	415	First Amphibians and Ammonites. Earliest trees and spiders
	Devonian		From *Devonshire*	30	445	Rise of Fishes
	Silurian		*Silures:* Celtic tribe of the Welsh borders	70	515	First spore-bearing land plants. Earliest known coral reefs
	Ordovician		*Ordovices:* Celtic tribe of north Wales	75	590	First fish-like Vertebrates. Trilobites and Graptolites abundant
	Cambrian		*Cambria:* Roman name for Wales	3000		Trilobites, Graptolites, Brachiopods, Molluscs, Crinoids, Radiolaria, Foraminifera. Abundant fossils first appear
Precambrian						Scanty remains of primitive invertebrates sponges, worms, algae, bacteria
						Rare algae and bacteria back to at least 3000 million years for oldest known traces of life

FIGURE 2. - Source: Milligan, G.C., 1977, The Changing Earth, McGraw-Hill Ryerson Ltd., Toronto.

appreciation of the fact that sufficient time has been available for the processes we are describing to have occurred, not only once, but repeatedly throughout the earth's history.

Further information on geologic time and its determination may be found in Reference 10, (Plummer and McGeary, 1979), Chapter 8, and Reference 6 (Holmes, 1978), Chapters 13 and 30.

4.1.3 Energy

Geologic time appears to have been adequate for the surface and subsurface processes that we recognize as taking place or having taken place on and in the earth.

The eruption of volcanoes, the melting of surface rock, the building of mountains and moving of large segments of the earth's crust are phenomena that require tremendous amounts of energy. Surface processes can be accounted for in terms of the energy provided by the sun and gravity. On the other hand, the subsurface processes operate below the influence of the sun (since rock is an excellent insulator) and the subsurface processes, in most cases, operate in opposition to the influence of gravity.

The energy required for subsurface processes is primarily in the form of heat and is derived from two sources: a) heat from the still slowly cooling interior of the earth, and b) heat derived from natural radioactivity. Observations on or near the earth's surface verify that heat increases with depth below that surface at the rate of about 1°F per 100 feet (or 2 to 3°C per 300 metres). These temperature changes with depths up to about 5 miles below the surface can be measured. Temperature changes

below that depth cannot be measured directly and have to be interpreted from other information such as the behaviour of seismic (earthquake) waves deep within the earth. Calculations from the measureable rate of temperature change and these more indirect methods it is believed the temperatures near the core should be about 4,000°C.

The total heat from both interior sources that is being released each year at the earth's surface is about 1,000 times the energy released each year in earthquakes and is about 250,000 times more than the energy of a 1-megaton nuclear explosion! (Press and Siever, 1978, Earth, W.H. Freeman & Co., San Francisco). This indicates that there is more than sufficient energy to 'drive' the subsurface geological processes. This interesting subject is dealt with in greater detail in the reference noted above (not included in your list) and in Reference 10, (Chapter 17, p. 307) and 6, (Chapters 2, 3).

4.1.4 Magmatism

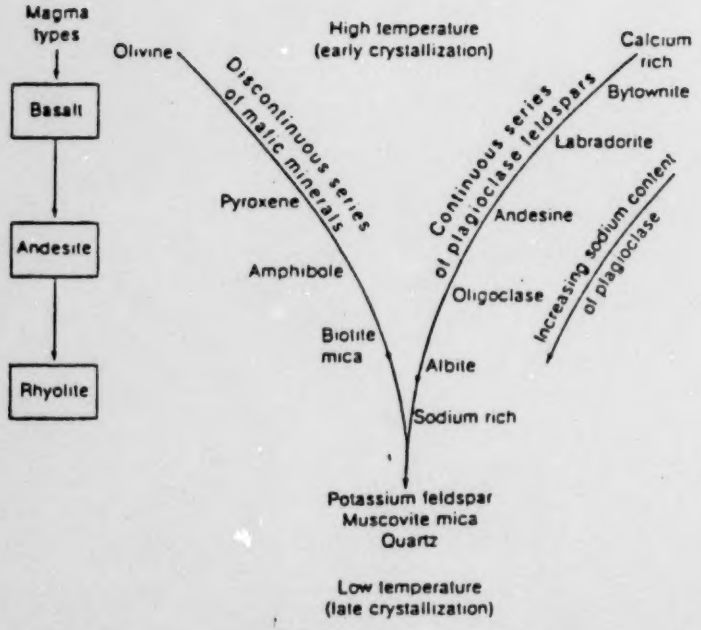
The existence of molten rock or magma, at high temperature and under great pressure, below the earth's surface will not be questioned by anyone who has witnessed a volcano erupting and pouring out its lava and/or ash. Examination of the cooled lava reveals minerals, textures and structures that are also found in rock outcrops far removed from any now active volcanoes and led early geologists to the conclusion that volcanic activity was common in the geological past and resulted in rocks that are widespread in areas where the volcanoes themselves have long ago been removed by erosion. N.B. is such an area and a look at the

geological map of the province (provided by the instructor) will show many areas, including that of Bathurst-Newcastle, in which volcanic rocks are abundant.

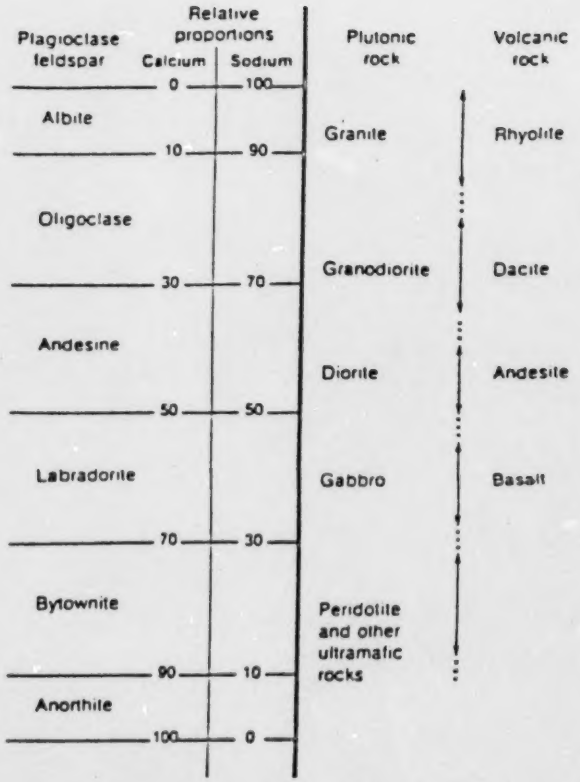
Volcanic rocks differ from one another in the minerals they contain, as well as in their textures and structures (as demonstrated by your rock collections and the descriptions/illustrations in your lab manuals, Chapter 3, p. 19). These variations in the mineral content of crystalline, volcanic rocks are also found in coarser-grained crystalline rocks (plutonic) that are not known to come from any active volcanoes but appear to have solidified from magma.

A Canadian mineralogist, N.L. Bowen, is largely responsible for our understanding of the variety of igneous rocks (volcanic and plutonic) formed as the result of crystallization from a more or less homogeneous primary magma derived from deep within, or at the base of, the earth's crust. (N.L. Bowen, 1956, The Evolution of the Igneous Rocks, Dover Publications, Inc., New York). Bowen experimentally melted the chemical compounds that are found in igneous rocks and controlled the cooling of the melted, artificial mass to produce synthetic 'rocks' that corresponded closely enough to natural igneous rocks to allow for confident interpretation of their origin, particularly of those plutonic rocks that form below the surface, out of direct view. (Fig. 3 depicts Bowen's Reaction Series).

Examples of plutonic rocks are widespread in N.B. having been exposed by long periods of erosion from formerly deep crustal zones that were uplifted in earlier mountain chains that crossed this region 100's of millions of years ago. The



Bowen's reaction series, showing how the sequence of fractional crystallization of a melt leads to the formation of differentiated magmas.



Igneous rock types are classified according to the relative proportions of the feldspars albite (sodium plagioclase) and anorthite (calcium plagioclase). The boundaries between rock types are gradual; the divisions between the feldspars are arbitrarily defined.

FIGURE 3. - Bowen's Reaction Series and Igneous Rock Classification
Source: Press and Siever, 1978, The Earth, W. H. Freeman and Company, San Francisco.

geological map of the province depicts the areas in which these plutonic rocks are now exposed. (Fig. 4 illustrates some of the common forms or modes of occurrence for igneous rocks).

The 'production' of the various igneous rocks from a common magmatic source of primary material is known as 'fractional crystallization' or 'magmatic differentiation' and the details are not included here. (Further information is available from Reference 10, Chapter 4, p. 62, and Reference 6, Chapter 5, p. 60, Chapter 11, p. 162 and Chapter 12, p. 188). It is an important concept, however, and the prospector should know, in a general way, that this process provides an explanation for the accumulation or concentration of some ore elements that would otherwise be distributed in magma in concentrations too low to be economically important.

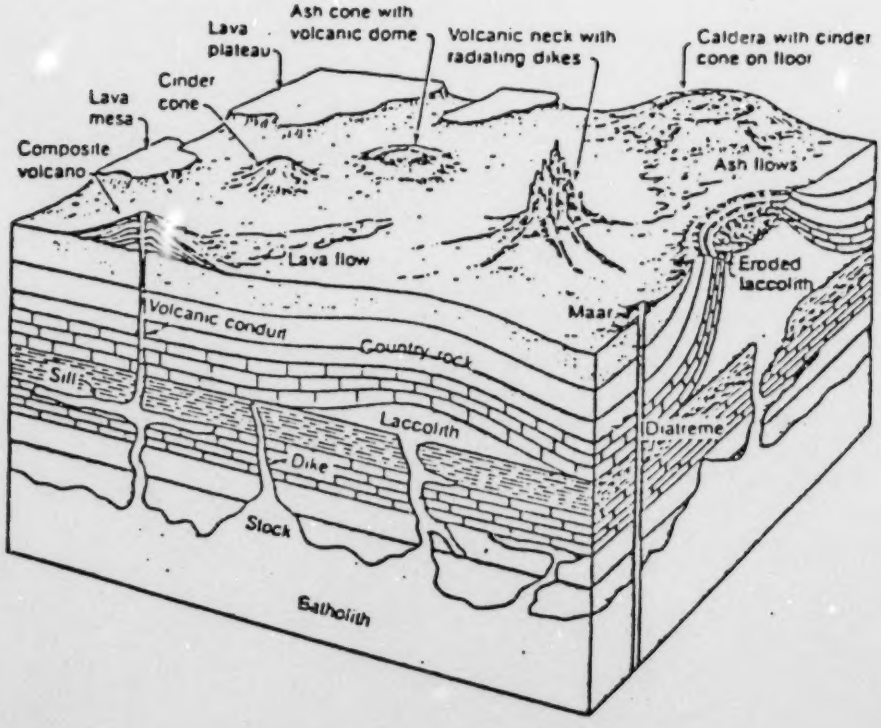


FIGURE 4. - Modes of Occurrence for Igneous Rocks
Source: As in Fig 3.

The ore deposits at Bathurst-Newcastle, Mt. Pleasant, the nickel-copper ore mineral occurrence at St. Stephen and many others in New Brunswick are believed to have been concentrated partly as a result of a magmatic crystallization. Further examples, on a world basis, may be found in Reference 9, Chapter 2, p. 22.

4.1.5 Metamorphism

Some understanding of the sedimentary rocks formed on (or close to) the surface and igneous rocks forming on the surface as volcanic deposits and below the surface as plutonic rocks leads logically to a consideration of another process that must take place below the surface. This additional process is required to account for the third major type or group of rocks 'metamorphic' that we now find widely distributed in outcrops of bedrock but which we do not see forming anywhere on the surface at present. Our knowledge of this subsurface process is based on two lines of investigation: a) a study of the 'products' of a process that results in characteristics that differ significantly from those of sedimentary and igneous rocks, and b) experimental or artificial reproduction of synthethic rocks that correspond closely to those found in nature.

As noted previously, dependable evidence exists for rising temperatures and pressures from the surface downward towards the interior of the earth. It requires little imagination to accept the concept that marked changes occur in rocks subjected to this increasing heat and pressure. These changes are particularly marked for sedimentary rocks such as shale, limestone, and

others, formed on the surface, under conditions of relatively low temperature and pressure, with which we are familiar.

At one end of the 'scale of change' produced in rocks as a result of increasing temperature and pressure is that required to convert unconsolidated sediments to solid sedimentary rocks. The difference between those two materials (e.g. gravel and conglomerate, sand and sandstone) is slight and can easily be accounted for by simple compaction and cementation effected by relatively shallow burial in progressively deepening basins. At the other extreme, is the complete melting of rock resulting from the much higher temperatures and pressures confidently predicted for deep zones within the crust or near its boundary with the mantle, some tens of kilometres below the surface. 'Metamorphic Petrology', the study of rocks of that group, is restricted to the changes between these two extremes or, in other words, changes that occur to essentially solid geological materials.

The 'agents' that effect the changes in pre-existing rock (igneous, sedimedntary, and other metamorphic rocks; refer again to the rock cycle and note the 'short circuits' possible in the cycle) are heat, pressure, and chemically active fluids contained within, expelled from, or circulating through, the original rock during other changes.

The pressure referred to in metamorphism is of two types: a) that resulting from the weight of overlying rock, i.e., 'confining' or 'hydrostatic' pressure, which at shallow depths below the surface becomes equal from all directions and thus, tends, primarily, to compact earth materials more densely, b) 'differential', pressure, is that applied from different

directions in different amounts. The difference in the type of dominant pressure applied to metamorphosing rocks results in the two major categories of these rocks, namely, non-foliated (confining pressure dominant) and foliated (differential pressure dominant).

Differences in metamorphic rocks also result from differences in the relative influence of heat vs. pressure. Rocks changed almost entirely by heat are common near the contacts of large plutonic rock masses such as batholiths and stocks. Changes of this type can also be observed and compared in fragments of pre-existing rock that have broken off and sunk into hot, molten magma that has later crystallized with these 'foreign' fragments (xenoliths) enclosed. Heated rocks subjected primarily to differential, rather than, confining pressure tend to have new platy or sheet-like minerals, such as biotite and chlorite, that have grown (in the solid state) preferentially at right angles to the direction of maximum applied pressure.

Prospectors should understand the general process of metamorphism and the fact that the metamorphic agents do not always operate uniformly or simultaneously. This latter fact, combined with differences in the original rocks, together result in a variety of metamorphic rocks. However, the most widespread metamorphic rocks are those that show evidence of having been influenced by both heat and differential pressure. When rocks of this type occur over large areas, such as some in the Canadian Shield, they are said to be regionally metamorphosed. Much of the rock exposed in the Canadian Shield is so highly metamorphosed that original characteristics cannot be recognized

and the origins therefore remain uncertain (Reference 4).

Your collections contain some metamorphic varieties of rock which should be reviewed with the guidance of your lab manuals (Chapter 5, p. 5). Additional information will be found in your References 6 (Chapter 8) and 10 (Chapter 7, p. 116).

Most of the older rocks in New Brunswick are metamorphosed to some degree and examples and locations of these will be indicated (by the instructor) on the Geological Map of the province.

4.1.6 Deformation of Rocks

The deformation of rocks into new spatial and geometrical positions and configurations, while retaining their other original characteristics, is common. Most consolidated rocks have been affected to some degree by this process which involves primarily mechanical stresses that exist in a crust that is continually undergoing change. As noted, the process is largely mechanical in nature and does not involve large amounts of heat as is common in metamorphism. The process may be considered as a very restricted type of metamorphism in which differential pressure is by far the dominant agent. The distribution of highly deformed rocks in mountain 'belts' that contain highly metamorphosed and plutonic rocks indicates that extensive mechanical deformation is associated with these other subsurface processes, as would be expected. Gentle deformation, however, is evident in many rocks far removed from these ('organic') belts.

The deformation of rocks is important to the prospector in that an understanding of the forms produced may help him/her to

unravel or decipher otherwise complex geology. More directly of interest, perhaps, is the fact that deformed rocks, in many cases, provide the sites in which ores and mineral fuels, such as oil and natural gas, are concentrated or mechanically 'trapped'. Ore deposits that result from the filling of cavities produced by rock deformation are by far the most numerous known.

All rocks behave, to some degree, elastically i.e. after being 'bent' or deformed slightly, they will return to their original shape and position once the pressure is removed. If the pressure is increased beyond the elastic limit for the rock, it may, under certain conditions, fracture or rupture. Under different conditions (high confining pressure, heat, fluids) a rock may deform 'plastically' in such a manner that it appears to "flow", without losing its cohesion or visible characteristics other than shape or the volume that it occupies. These two types of permanent deformation are known as 'brittle' and 'plastic' respectively. The manner or extent by which rocks deform depends on several variables: heat, the physical properties of the rock, the magnitude and direction of the differential pressure applied, the amount of confining pressure being applied, time and the availability of fluids in the 'system'.

In general and simplified terms, brittle (low temperature) deformation produces faults, fractures and similar planar 'breaks' in the rocks. Plastic (higher temperature) deformation produces various types of 'folds'.

Structural geology, or the study of rock deformation and the forms this deformation yields, is a major branch of the geological sciences. For this program, only the geometrical

aspects will be considered, that is, the forms in this process. A more detailed treatment of this subject will be found in Reference 6 (Chapter 9, p. 126) and 10 (Chapter 15, p. 262).

Identifying and describing faults and folds, that represent deformations or departures from the predeformation position or form of rocks, requires a method of recording the position of planar features in space. In this context the size of the planar features is ignored and only the position of 'attitude' is sought. Planes in space can be identified in terms of their strike and dip. These terms are illustrated and described in Reference 6 and 10 and in your lab manuals. They are also illustrated in Figure 5. The ability to determine dip and strike is an essential skill for the prospector. Slides and supervised practice will assist in developing this skill. (A diagram illustrating the often-used terms, 'hanging wall' and 'foot wall' of faults is provided in Fig. 6).

To recognize that a rock or sequence of rocks has been deformed from its original position or form, requires that the observer be able to determine that original position or form. Deformation results in secondary structures superimposed on original or primary structures that were produced in the rock at the time it formed. The most obvious, widespread, and useful primary structure is bedding in sedimentary rocks. The original bedding planes in sedimentary rocks were essentially parallel to sea-level at the time these deposits were laid down. They thus serve, where they can be recognized, as a reference to the original position of the rock before it was deformed.

In highly deformed rocks the bedding may actually be

aspects will be considered, that is, the forms in this process. A more detailed treatment of this subject will be found in Reference 6 (Chapter 9, p. 126) and 10 (Chapter 15, p. 262).

Identifying and describing faults and folds, that represent deformations or departures from the predeformation position or form of rocks, requires a method of recording the position of planar features in space. In this context the size of the planar features is ignored and only the position of 'attitude' is sought. Planes in space can be identified in terms of their strike and dip. These terms are illustrated and described in Reference 6 and 10 and in your lab manuals. They are also illustrated in Figure 5. The ability to determine dip and strike is an essential skill for the prospector. Slides and supervised practice will assist in developing this skill. (A diagram illustrating the often-used terms, 'hanging wall' and 'foot wall' of faults is provided in Fig. 6).

To recognize that a rock or sequence of rocks has been deformed from its original position or form, requires that the observer be able to determine that original position or form. Deformation results in secondary structures superimposed on original or primary structures that were produced in the rock at the time it formed. The most obvious, widespread, and useful primary structure is bedding in sedimentary rocks. The original bedding planes in sedimentary rocks were essentially parallel to sea-level at the time these deposits were laid down. They thus serve, where they can be recognized, as a reference to the original position of the rock before it was deformed.

In highly deformed rocks the bedding may actually be

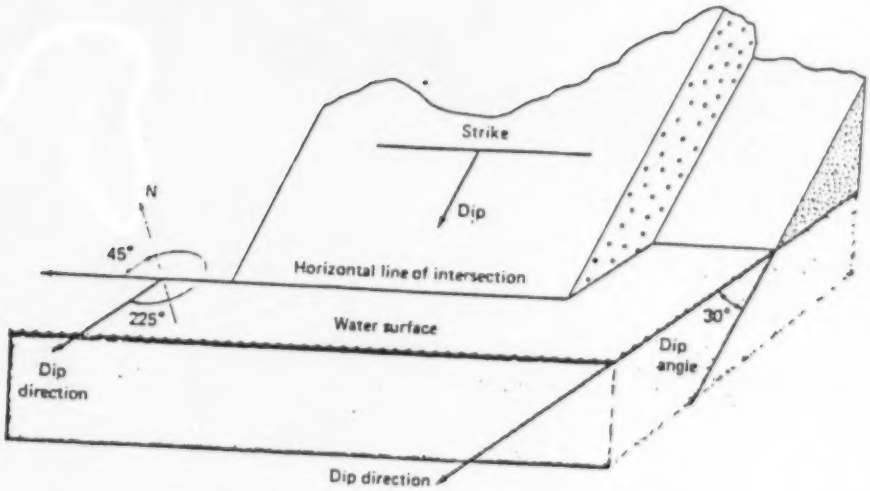


FIGURE 5. - Strike, Dip and Dip Direction.
Source: Judson, Defreyes and Hargraves, 1976, Prentice-Hall Inc., New Jersey.

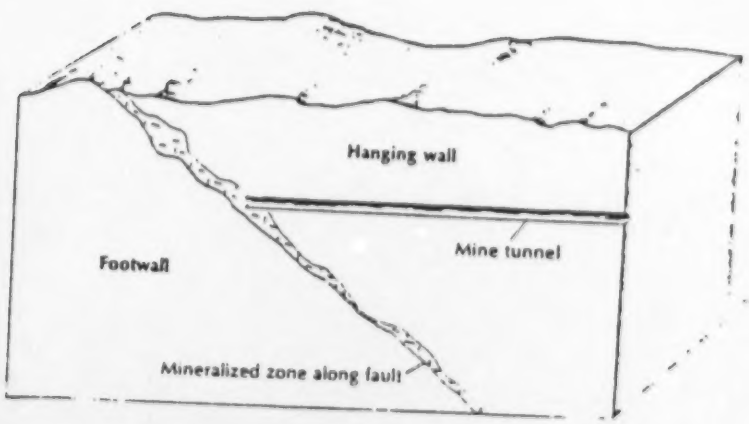


FIGURE 6. - Hanging and Foot walls of a Fault.
Source: Birkeland and Larson, 1978, Putnam's Geology, 3rd Ed., Oxford University Press, New York.

overturned, i.e. the beds in sedimentary rocks may 'face' downwards having been rotated through more than 90° from their original position parallel to sea-level. In such cases, it is necessary to identify 'tops' or the upper surfaces of beds in order to 'reconstruct' the original position of the beds and, thus, the amount of deformation to which they have been subjected. (This will be demonstrated by the instructor).

Another structural feature essential in the understanding of the geologic history of an area is the unconformity. (Examples will be found in your lab manuals and in slides described by the instructor). Unconformities represent 'breaks' in the sedimentary history of an area resulting from uplift or deformation of surface areas that were below sea-level and thus receiving sediment, to elevations at which erosion occurred and removed or interrupted the sedimentation. The uplift generally involves deformation of the earlier strata then erosion of its forms and shapes to yield a relatively flat surface representing a 'new' sea-level parallel to which younger sediments are now laid down horizontally but at an angle to the earlier deformed rocks.

An understanding of faults, folds, and unconformities will require some study and practice in visualizing them, recognizing them on maps and in the field, and assessing their significance in the geological history of an area, particularly as they may contribute to or control the concentration of ore minerals and mineral fuels. A treatment of the geometry of secondary structures is provided in Reference 2.

A N.B. example of ore concentration in faults and fractures

is that of the Lake George Antimony Mines, about 25 miles west of Fredericton. The oil and natural gas deposit at Stoney Creek near Moncton is an example of control or concentration effected by a fold structure. Many other smaller, subeconomic occurrences of structurally controlled mineralization, particularly in faults and fractures, are known.

Further information of the structural control of ore bodies may be found in References 4 and 9 in both of which additional references are given to more specific examples in Canada and on a world wide basis respectively.

Chapter 16 of your lab manuals is devoted to Structural Geology and it includes a series of exercises with maps that will be found helpful in understanding this important subject. At this stage in this program, it is suggested that attention be concentrated on pp. 136 to 149 inclusive.

4.1.7 Summary

An attempt has been made in the foregoing to introduce the trainee to some of the most complex and, therefore, difficult to understand concepts in the geological sciences; the interior of the earth, geologic time, internal energy, magmatism, metamorphism and rock deformation. It is not expected that instant competence will result from the reading of these notes or even the references cited in them. The notes and demonstrations recommended to accompany them are designed to acquaint the trainee with some of the less obvious aspects of the geological processes and to indicate, in a preliminary way, the significance of them to his/her specialized interest as a prospector.

4.2.0 Geologic Maps

4.2.1 Introduction

The geologic map is the basis upon which the prospector organizes the program that may lead to an ore discovery.

Geological maps, on some scale, are available for the whole of Canada. In N.B., geological maps for the whole province and fairly detailed geological information in maps and reports for some specific areas are both available from the office of the Department of Natural Resources. Furthermore, geological, geophysical, and geochemical information is being continually improved and updated.

Geological maps and reports are generally issued for individual areas of various sizes and on corresponding scales. In additon, there are many general reports and maps (Reference 4) as well as those serving more specialized interests (Reference 11). Prospectors should be aware of the sources of all geological data for the areas of their interest and they should check periodically for new issues.

Reading and interpreting geological maps (and the reports that accompany many of these maps) is a skill based on knowledge and experience. Improvement in this skill should be expected to continue throughout the active life of the prospector. The serious prospector will spend a good part of the winter season studying geological maps for the purpose of more intelligently concentrating the field work in what he/she has interpreted to be favourable ground. Otherwise, the prospector is depending primarily on luck.

4.2.2 Scales and Data

As with topographic maps, data has always to be selected when a representation of an area on the surface is presented in the form of a map that is ,for example, 1/50,000th of the actual area reported upon. This sacrifice or selection of information increases with the increase in size of the area on the ground relative to that of the map. For example, the Geological Map of N.B., on a scale of 1:500,000, represents 500,000 feet (approximately 100 miles) on the ground by one foot on the map. Expressed the other way, one inch on the map represents approximately 8 miles on the ground. Maps on such a scale are useful for obtaining very general information, regional patterns, geological history, comparisons over great distances etc. Such maps would not be expected to show actual location of outcrops from which the major or regional features were interpreted. The prospector must, therefore, learn what to expect from a review of geological (and other) maps on various scales.

For practical purposes in the search for ore mineral occurrences, the prospector usually wishes to have outcrops located on the maps he uses. Outcrops are seldom shown on maps less detailed than one inch equals one mile, or 1:50,000.

4.2.3 Outcrops and Geological Contacts, Faults, Folds, etc.

The density and distribution of outcrops located on a geological map indicate the degree of certainty or accuracy with which the geologist can place structural features such as contacts between rock formations (mappable units) faults, fold

axes, unconformities, etc. so important to the prospector as possible controls for concentration of ore. Different symbols are also employed to show where these features are 'defined', 'approximate' and 'assumed'. These distinctions on a geological map are significant since they may indicate areas or zones on the ground in which the more detailed and less time-constrained work of the prospector may reveal additional outcrops, more exact locations for structural features and even ore mineralization missed by the geological mapping party.

Geological mapping parties generally map systematically, on a grid that is designed with traverses (lines followed by pace and compass) that cross the general strike of formations at right angles. (The general strike is taken from earlier, less detailed geological maps, if available, and if not, from topographic maps or aerial photographs on which the 'grain' of the country probably reflects the prevailing structure in the underlying rocks of the area). The spacing of these traverses on the ground is generally 1/2 the map scale. In other words, if the map is published on a scale of one inch equals one-half mile, the distance between two traverse lines on the ground will be approximately one-quarter mile. This is a generalization and many variations are possible. However, on maps that show the actual outcrops encountered in the geological survey, it is often possible for the prospector to plot the actual traverses made by the geologists and thus know where the geologists have been and perhaps more importantly where they have <u>not</u> been, in their survey. (Some maps show actual traverses but these are generally removed before publication).

4.2.4 Interpretation of Geological Maps

The interpretation of geological maps, by and for the prospector, involves all the knowledge of rocks, minerals, surface and subsurface processes he/she has been able to acquire. The objective of the interpretation is to obtain from the geological map(s) 'clues' that indicate possible locations for the concentration of ore minerals or mineral fuels. Recognizing that ore concentrations are anomalies in the earth's crustal materials and that these anomalies or uncommon situations are generally expressed in irregularities of geological (geophysical, geochemical) features, the prospector is particularly attracted to portions of a geological map in which irregularities or abnormalities of structure, rock type, etc. are indicated.

If 'irregular' features, e.g. changes in strike of contacts, faults, folds, unconformities, pinching out and thickening of rock units, are indicated on a geological map, they represent areas worthy of investigation on the ground. If geological anomalies are not indicated on a geological map, it does not mean necessarily that they do not exist. The direction of traverses by the geologist might result in missing them. The scale of traversing and the map itself may not be sufficiently detailed to locate small irregularities which may, nevertheless, be adequate for high grade ore localization. (Find the dimensions on the Brunswick No. 12 orebody and plot that orebody on a geological map of the area provided by the instructor). If ore mineralization or ore deposits are known in an area that has been geologically mapped, the prospector will look on the map for any

geological features that appear to be associated with the mineralized locations. (It isn't necessary to understand the origin/history of the 'features'). Moving away from the zones of known mineralization, he/she will look for comparable features depicted in areas where mineralization has not been identified. Here again, geologists may miss features such as close-spaced fractures, joints, alteration, etc. that the prospector may find on the ground.

No two ore bodies are identical and, similarly, no two geological maps are the same. Indeed geological maps of the same area by different authors and/or on different scales may depict different geology. The prospector must, therefore, take from geological maps all information that is likely to aid his/her search but the wise prospector will also be aware of the fact that geological maps are imperfect and they are generalizations or representations of some, but not all, features that can be observed on the ground.

Interpretation of geological maps is the most advanced skill the prospector develops and practice with maps at this stage is probably more useful than describing ore controls and the techniques for locating them. On the other hand, the beginning prospector should not be discouraged by his limited knowledge of geology, ore deposits, etc. There are many examples wherein common sense, limited skill and careful ground search have resulted in 'finds'.

4.2.5 Exercises

Familiarize yourselves with the geologic map symbols listed

on p. 139 of your lab manuals. (This should be done in the examination of any geological map since the symbols used vary somewhat). Also note the legend for each map in your lab manuals pp. 150-160 inclus. and compare the legends with the geological time-scale (Fig. 1 of these notes). The problems in your manuals should be attempted, in your own time, after completing, with the help of the instructor, the following exercises.

a) Exercise with Geologic Profiles (see pages 28-31 inclus.)

b) Exercise, Geological Map Sussex Area* (see page 32).

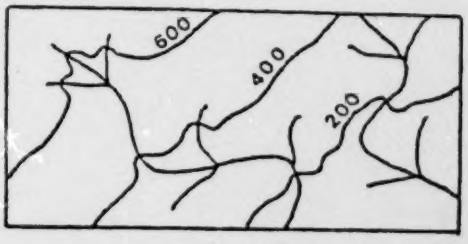
*Note the whole map from which Fig. 7 is taken will be available from the instructor.

a) Exercise with Geologic Profiles (UNB)

With a topographic profile, the viewer has the shape or form of the surface. While this is useful, it lacks some very important information which may be critical for the prospector and others. By combining the topographic profile with a geological profile, the prospector has information not only regarding the 'shape' of the surface but also regarding the material that underlies the surface and may be causing that particular surface form.

Looked at from the subsurface point of view, rock types underlying an area markedly influence its topography; rocks resistant to weathering stand up in ridges, hills, mountains whereas those that weather easily occupy areas of low elevation or depressions: valleys, lake bottoms, etc. The study of land forms and the underlying rock formations that influence them is called, "geomorphology", and it is an important branch of the geological sciences.

In addition to the type (or composition, and hence resistance, to weathering) of rock, the structure (the orientation of the various rock types in space (below the surface) influences the shape of the surface of an area. For example, a flat (horizontal) bed of sandstone underlying an area will tend to yield a flat, close-to-horizontal surface. Alternating beds of hard and soft rock, deformed in such a way as to be tilted to the vertical, yield a topography of parallel ridges and valleys.



SURFACE

PROFILE (Section)

horizontal bed of hard (resistant) sandstone

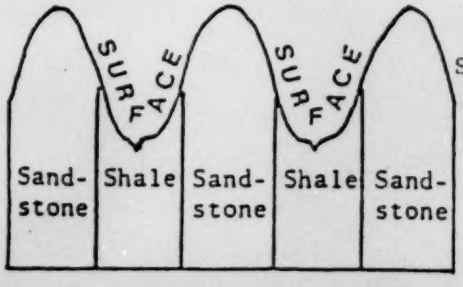
horizontal bed of soft (easily eroded) shale

another bed of hard sandstone

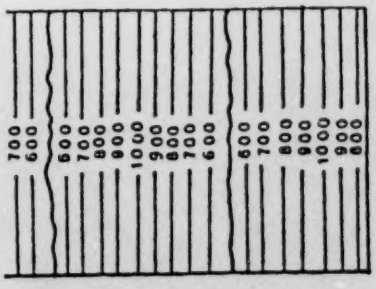
SURFACE PLAN

Relatively smooth surface. Rivers wande with no obvious contro of direction.

Section

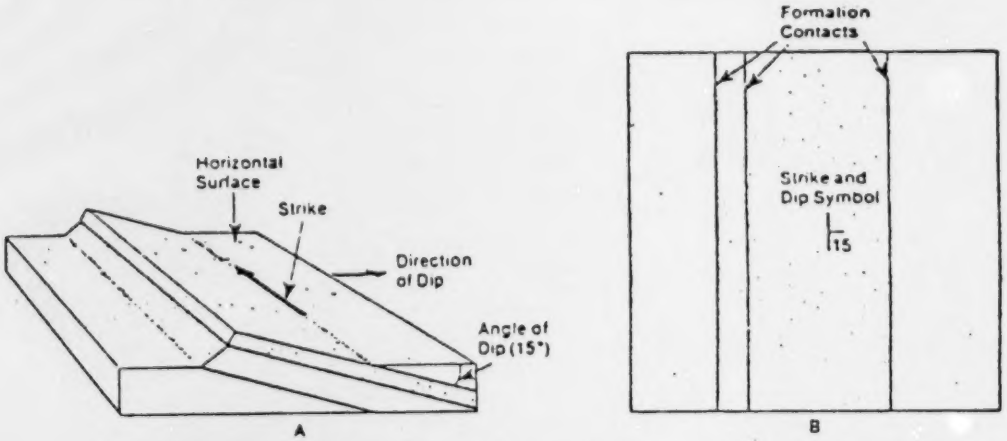


SURFACE PLAN

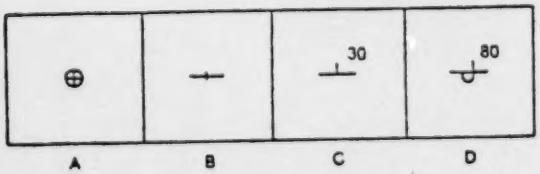


Ridged surface produced by alternating resistant and weak strata interbedded and deformed into vertical position.

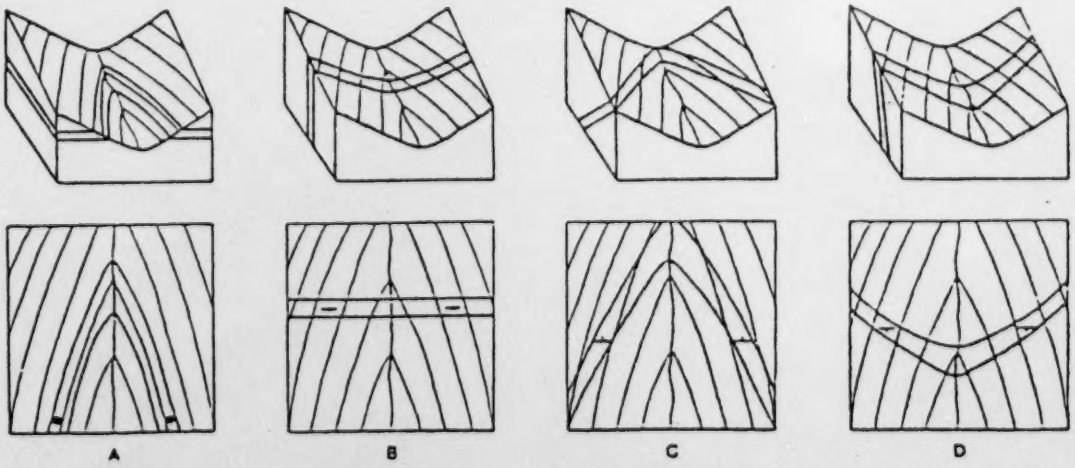
To indicate the orientation of rock formations below the surface, geologists use symbols known as, 'dip and strike'. These symbols show the extent to which underlying formations are out of horizontality. They are based on observations made in the field on outcrops of bedrock (crust) and then projected on the surface and at depth below it. The following diagrams illustrate how dip and strike are measured in the field and how they indicate the orientation of rocks below the surface. (Do not proceed with this exercise until you understand the use of these symbols. It's important to appreciate that you don't have to know how, when or why the formations deformed. All you are concerned with here is the geometry of their positions now).



Diagrams illustrating strike and dip. (A) Block diagram of four inclined formations. (B) Geologic map showing surface distribution of the four formations. Their strike and dip is indicated with symbols explained in Figure 17-2.



Symbols used to indicate strike and dip of rock layers on geologic maps. (A) Horizontal rock layers. (B) Vertical rock layer; strike direction indicated by long line drawn with correct compass direction. (C) Dipping layer; dip direction indicated by "tick" and amount of dip listed in degrees. (D) Overturned dipping layer; because layer has been rotated through more than 90° its dip direction is shown with a curved "tick."



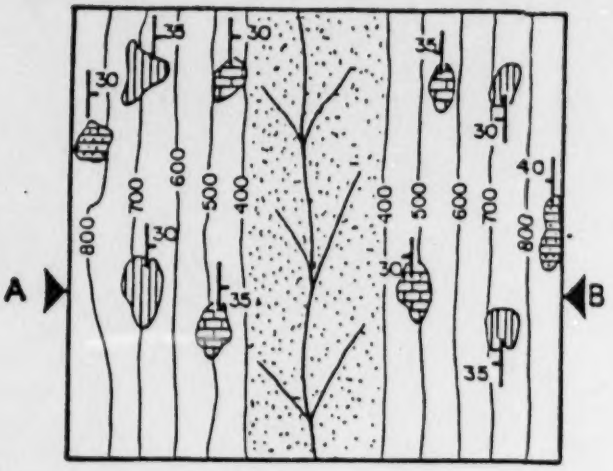
Block diagrams (top) and geologic maps (bottom) illustrating relationship between bedrock attitude and topographic variations. Shaded area represents outcrop pattern of one formation. Strike and dip symbols shown on geologic maps. (A) Horizontal rock layer. (B) Vertical rock layer. (C) Rock layer dipping upstream. (D) Rock layer dipping downstream.

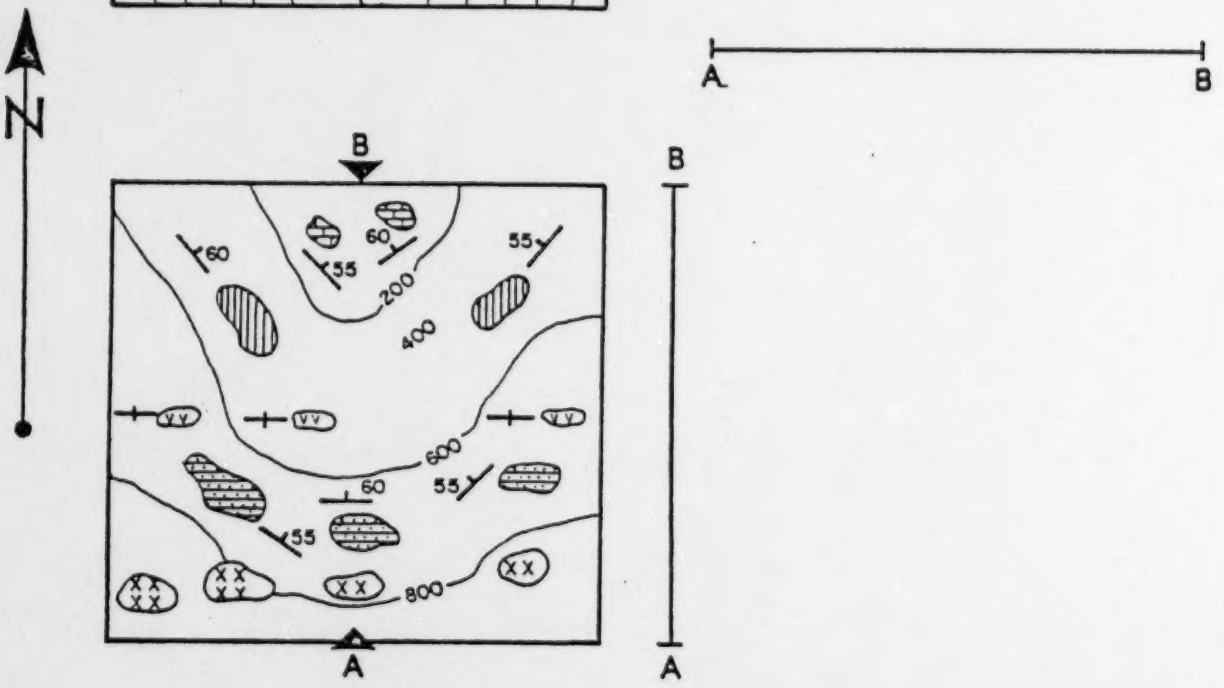
Two small simple sketches are given on the next page. These could be portions of a geological map with a horizontal scale of, say, one inch equals 500 feet. Outcrops of various rock types are plotted on the sketches and their dips and strikes are recorded where these can be observed on some planar feature within each rock type.

1) Colour in solidly the outcrops of each rock type.

2) Extend (in light colour) the probable distribution of each rock types (based on the dips and strikes and the distribution of outcrops).

3) Draw a combined topographic and geologic section for each sketch.





Glacio - fluvial deposits

Grey Sandstone

Limestone

Mafic dyke rock

Mafic lava flows

Granite

b) Exercise, Geological Map Sussex Area)*

Part of a geological map of the Sussex Area of N.B. is provided on the following page. The legend and list of symbols used with this map are also reproduced here. This geological map has topographic contours in addition to the location of actual outcrops (shown as X's).

Color the outcrops shown in solid colour for each of the formations, then colour lightly the areas interpreted (from the outcrops) as being underlain by each of the formations. Note the different types of contacts illustrated. (Check with the coloured copy).

Note the attitudes (dips and strikes) of the several formations. Do these attitudes parallel the contacts? Why?

Approximately what percentage of the area depicted has outcrop located on the map? (Roughly circle areas that contain groups of outcrop close to or less than one-quarter mile from one another).

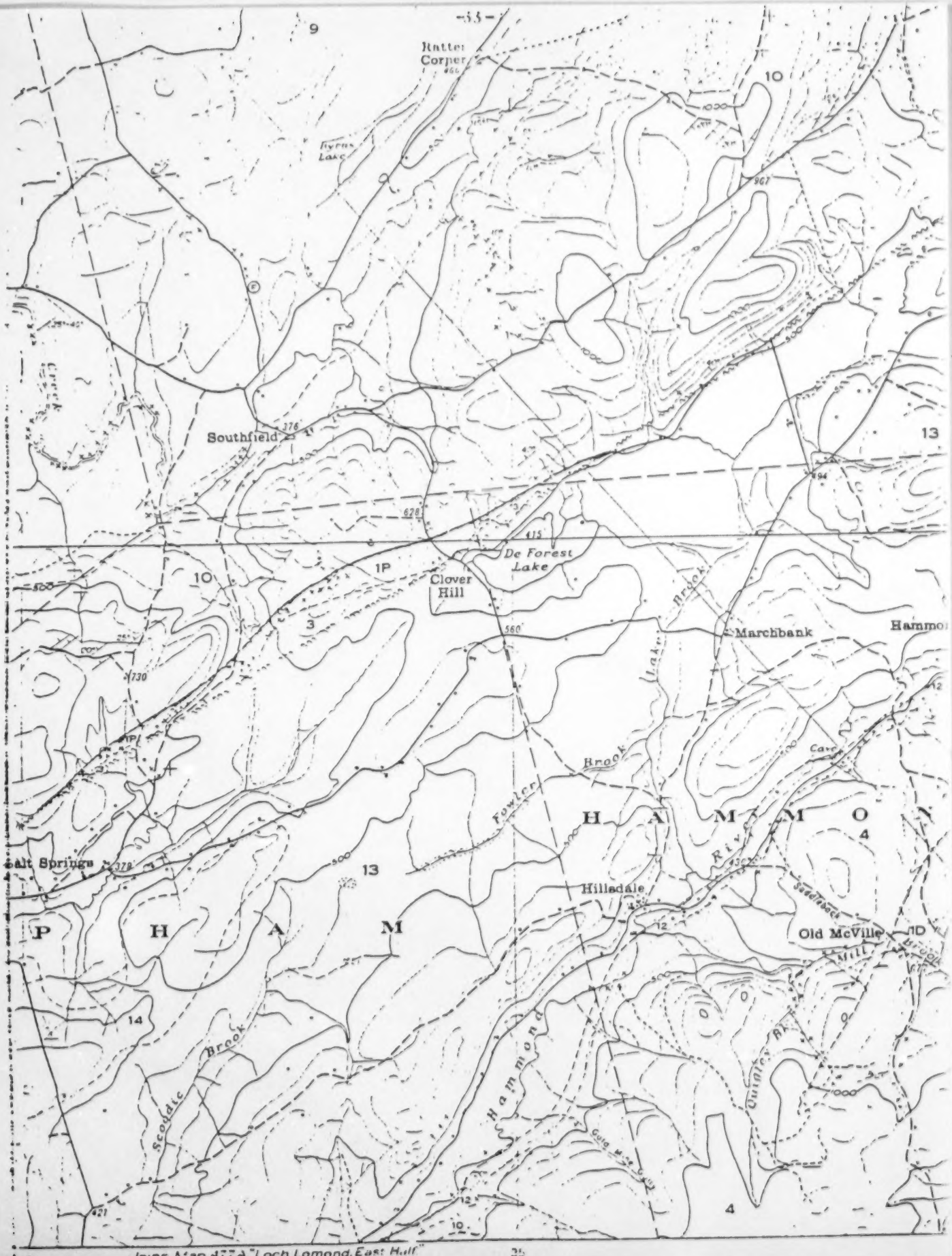
Draw a topographic and geological cross section from Southfield to Old McVille.

Along what 'traverses' has the geological information contained on this map been obtained?

What zones or features would you consider worthy of detailed prospecting in this area? Why? What ore minerals or mineral fuels might you expect to occur here?

What additional information would you like to see on a map of this scale?

*Note the whole map from which Fig. 7 is taken will be available from the instructor.


Ratter Corner
Byrnes Lake
Southfield
De Forest Lake
Clover Hill
Marchbank
Hammo
Fowler Brook
Salt Springs
Hilladale
Old McVille
Saddleback Mill Brook
Scodaic Brook
Hammond River
Quinn's Rd
Gulq Mine Creek
P H A M
H A M M O N
9
10
13
14
4
3
1P

LEGEND -- SUSSEX AREA MAP

PALÆOZOIC

CARBONIFEROUS

PENNSYLVANIAN

PETITCODIAC GROUP

14 — *Grey sandstone, shale, and conglomerate*

MISSISSIPPIAN AND (?) PENNSYLVANIAN

HOPEWELL GROUP

13 — *Red conglomerate, sandstone, and shale*

MISSISSIPPIAN

WINDSOR GROUP

12 — *Mainly limestone and gypsum*

MONCTON GROUP

10 — *Grey to red conglomerate, sandstone, shale, and nodular limestone*

9 — *ALBERT FORMATION: grey shale, sandstone, conglomerate, and limestone*

KENNEBECASIS GROUP

11 — *Grey to red conglomerate, sandstone, and shale*

ORDOVICIAN AND/OR SILURIAN

Red and grey shale; volcanic rocks

PRE-CARBONIFEROUS

6 — *Slaty sedimentary rocks; minor volcanic and intrusive rocks*

CAMBRIAN

ST. JOHN GROUP

5 — *Red and grey breccia, sandstone, and shale*

KINGSTON GROUP

7 — *Volcanic rocks*

PROTEROZOIC

COLDBROOK GROUP

4 — *Acid to basic volcanic rocks*

ARCHÆAN

GREEN HEAD GROUP

Graphitic schist; dense dark quartzite, limestone

PROTER(

4 *Acid to basic volcanic rocks* 35

LEGEND -- SUSSEX AREA MAP (continued)

ARCHÆAN

GREEN HEAD GROUP

Graphitic schist: dense dark quartzite, limestone

Gabbro. Probably Devonian

Granite: 1P. probably Precambrian: 1D. probably Devonian

Heavily drift-covered area

Sink hole S.H.

Observed rock outcrop

Bedding (horizontal, inclined, vertical)

Fault

Glacial striæ

Fossil locality F

Provincial highway NO. 2

Road and buildings

Road not well travelled

Trail

Church

School

Post Office

Cemetery

Triangulation station

Lighthouse L.H.

Power transmission line

County boundary (approximate)

Parish boundary (approximate)

Intermittent stream

Marsh

Contours (interval 100 feet) 500

Height in feet above Mean sea-level 317'

Geology by F.J. Alcock 1941, 1943; G.S. MacKenzie, 1942. Descriptive notes by F.J. Alcock

Base-map compiled by the Topographical Survey 1944, from Sussex map published in 1927, and reprinted in 1939 by the Hydrographic and Map Service. Cartography by the Drafting and Reproducing Division, 1945.

35'

45°30'

66°